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Olympic Lightweight and Open Rowers possess distinctive physical
and proportionality characteristics

Running title: Physical and proportionality characteristics of Olympic Rowers

D.A. Kerr[1], W.D. Ross[2], K. Norton[3], P. Hume[4], M. Kagawa[1,] T.R. Ackland[5]

[1]Curtin University of Technology
[2]University of Western Washington
[3]University of South Australia
[4]Auckland University of Technology
[5]The University of Western Australia

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Corresponding author:

Dr Deborah Kerr
School of Public Health
Curtin University of Technology
GPO Box U1987, Perth 6845
Australia
Ph +61 8 9266 4122
Fax +61 8 9266 2958
Email d.kerr@curtin.edu.au

Abstract

Rowers competing at the 2000 Olympic Games were measured on a battery of 38 anthropometric dimensions. The aim was to identify common physical characteristics that may provide a competitive advantage. There were 140 open-class (O) male rowers, 69 female O rowers and 50 lightweight (LW) males and 14 LW females. Body mass, stature and sitting height were significantly different ($p<0.01$) between the O and LW rowers, as well as a comparison group of healthy young adults (N), for both males and females. After scaling for stature, O rowers remained proportionally heavier than N with greater proportional chest, waist and thigh dimensions ($p<0.01$). Rowers across all categories possessed a proportionally smaller hip girth than N ($p<0.01$), which suggested the equipment places some constraints on this dimension. Top ranked O male rowers were significantly taller and heavier and had a greater sitting height ($p<0.01$) than lower ranked O male rowers. They were also more muscular in the upper body as indicated by larger relaxed arm girth and forearm girth ($p<0.01$). For the LW male rowers only proportional thigh length was significantly greater in the best competitors ($p<0.01$). In the female O rowers, the skinfold thicknesses were significantly lower in the more highly placed competitors. Rowers in this sample demonstrated distinctive physical characteristics that distinguish them from the comparison group and other sports performers.

Introduction

The performance achievements of Olympic athletes come from a unique combination of inherited traits and capacities developed through training. Identifying factors such as physical size and structure, which may result in the best performance, can assist the exercise scientist and coach in selecting and developing talented athletes (Ackland 2005). In the sport of rowing, talent identification programmes have attempted to identify potential young athletes using various performance variables, including several anthropometric measurements (Hahn 1990). There is, however, a lack of anthropometric data collected at either World Championship or Olympic Games level to facilitate this talent identification approach.

The last comprehensive anthropometric survey of rowers was the Montreal Olympic Games Project (MOGAP) conducted at the1976 Olympic Games (Carter 1982). Included in this sample were data on 71 male and 51 females rowers, but lightweight rowing was not an Olympic event at this time. Since 1976 there have been considerable developments in training methods and rules for participation. It is possible that these factors have resulted in corresponding changes in the optimum athletic physique required for rowing events.

A unique opportunity to gather this information was presented in August/September 2000, during the Sydney Olympic Games. With the official support of the international rowing governing body, and funding from the IOC Medical Commission, 38 anthropometric measurements were obtained from 273 rowing competitors. Of these competitors, 74% were ranked in the top 10 Olympic finalists, making this the most current and comprehensive survey of elite rowers.

The aim of this study was to analyze the anthropometric characteristics of Olympic rowers in order to determine whether they possess unique physical characteristics that provide an advantage for their sport and distinguish them from the normal population. In addition the proportional differences in physique between lightweight (LW) and open (O) rowers were examined. This information can be most effectively used for talent identification and development programmes (Ackland 2005).

Methods

Participants

A total of 190 male and 83 female rowers were measured using a battery of 38 anthropometric dimensions in the 15-day period prior to the start of the Olympic competition (Ackland et al. 2001). Rowers from 30 countries competed in 14 events from single sculls to eight-person crews. A normative sample (N) of randomly selected, healthy, young adult males (n = 42, Kagawa (2005) and females (n = 71, Kerr (1996) was also included as representative groups for comparison. The comparison subjects were of Caucasian background and varied in how active they were but were not elite athletes.

While the initial contact was made through team officials, rowers were invited to take part in this study on an individual basis. All participants read and signed a consent form prior to measurement and were recruited under the patronage of the Human Rights Committee of The University of Western Australia.

Data collection

Before the data collection phase commenced, inter-tester technical error of measurement (TEM) values for each of the participating anthropometrists (International Society for the Advancement of Kinanthropometry - ISAK level 2 or 3) compared to the criterion anthropometrist (ISAK level 4) were calculated for every variable (Norton & Olds 1996). For inclusion on the measurement team, anthropometrists were required to demonstrate inter-tester TEM scores less than 5% for skinfolds and less than 1% for the other measures of segment lengths, breadths and girths. Further assistants were recruited to act as data recorders and marshals during the testing phase.

A mobile laboratory was despatched to accommodation venues for each of the teams so that rowers could be measured in a single session during a rest period within their training schedule. Before being measured, each rower completed demographic and crew position information.

Anatomical landmarks were located and marked by the criterion anthropometrist, before the rower was directed to one of five stations for the measurement of 38 anthropometric dimensions (nine skinfolds, 10 direct lengths, 12 segment girths, six breadth measurements and body mass). All variables were measured on the right side of the body in duplicate (when time permitted) and the mean value was recorded. On occasions when the time available was restricted, single measures for length and breadth variables were recorded. The standard procedures for each measurement, as defined by the International Society for the Advancement of Kinanthropometry (ISAK) and reported in Bloomfield et al. (1994) and Norton and Olds (1996), were followed at all times. The nine skinfold sites measured were triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medical calf and mid-axilla skinfold. Upper arm length was the distance between the acromiale and radiale landmark and forearm length was the distance between the radiale and stylion landmark. Thigh length was the distance between the trochanterion and tibiale laterale and lower leg length was the distance between the tibiale laterale and the floor. The shoulder breadth was defined as the distance between the most lateral points on the acromion processes, and hip breadth was the most lateral points on the iliac crests. Arm, chest, waist, mid-thigh and calf girth were all corrected for the skinfold at the site using the following formula: corrected girth = girth – (π x skinfold thickness). Using this formula arm girth was corrected for triceps skinfold, chest girth corrected for subscapular skinfold, waist girth corrected for abdominal skinfold, mid-thigh girth corrected for front thigh skinfold and calf girth was corrected for medial calf skinfold. The corrected girth provides a better indicator of musculoskeletal size at each site (Martin et al. 1990).

Data analysis

Absolute body size statistics were calculated for all Olympic LW and O competitors. The measurement sites used to calculate the sum of eight skinfolds were triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medical calf. Information regarding relative size was gained through calculation of Phantom Z-scores (Zp) (Ross & Marfell-Jones 1991; Ackland & Bloomfield 1995). Zp indicate the relative magnitude of a physical characteristic with respect to the subject's stature. The somatotypes were calculated using the method of Carter and Heath (Carter & Honeyman Heath 1990).

Absolute and relative size differences were compared between the three groups (O, LM and comparison groups). As the assumption for homogeneity of variance was violated in this sample, a non-parametric test (Kruskal-Wallis test) for K independent samples was applied. A level of significance was set at $p<0.01$ to take into account for multiple comparisons. The sample of O and LW rowers was then stratified for comparison of those males ranked in the top seven (Best) places (includes sweep and scull rowers in events from one to eight crew members) with the remaining competitors (Rest). While both O and LW male rowers were included, the analysis was only performed for female O rowers due to sample size restrictions for LW. A series of univariate analyses of variance (ANOVA) was used for this comparison, with separate analyses performed for male and female rowers. Post-hoc comparisons were made using Tukeys HSD. For these multiple comparisons, a full Bonferroni correction was not used as this method is known to be conservative. Instead, a level of significance was set at $p<0.01$ (i.e., 0.05 ÷ 5) and considered a good compromise between accounting for multiple comparisons with a moderate sample size, without increasing the risk of Type II errors. Statistical power was calculated for each analysis.

Results

Absolute body size and somatotype

Mean values and ANOVA results for the anthropometric variables are shown in Table 1. There was a significant difference in body mass, stature and sitting height ($p < 0.01$ respectively) between the O and LW rowers among both male and female competitors respectively, with O rowers being greater in size and mass. The LW male and female rowers were closer in stature to N than the O rowers. Nevertheless, the standard deviation in stature and body mass were smaller for the rowers, particularly the LW rowers, compared with N (Figures 1 and 2). Furthermore, when compared to athletes from other sports, the standard deviation in stature and body mass was also much lower for both male and female LW rowers.

Insert Table 1, and Figures 1 and 2 about here

No arm span data were available for N, so this parameter is not included in Table 1. However, mean arm span for the O male rowers (mean ± SD) was 200.3 ± 6.2 cm compared with 187.6 ± 4.9 cm for the LW males ($p < 0.001$). Among the women rowers, the arm span was 183.8 ± 5.2 cm for the O rowers and 170.5 ± 4.3 cm in the LW competitors ($p < 0.001$). In all rowers, the arm span was greater than their height.

With regard to the sum of eight skinfolds, the O and LW rowers were leaner for both the male and female competitors compared to N. The LW males were, in turn, significantly leaner than the O rowers ($p = 0.01$), but for the females there was a trend only ($p = 0.05$).

The differences in stature and body mass described above, were also displayed in several measures of limb lengths and girths respectively. Limb lengths were similar between the LW rowers and N, reflecting similar overall skeletal size (Table 1). Both male and female O rowers had longer segments compared to LW and N at all sites.

Among the male LW rowers there was little difference in corrected girths and other absolute girth measures compared with the N subjects, except for the corrected mid-thigh girth, indicating greater muscularity at this site. Both LW males and females had a smaller hip girth compared with N and O rowers, indicating possibly less adiposity and a smaller physical structure of the hips. In the males, the N had a significantly smaller shoulder breadth compared with the LW and O males, whereas for the female sample, the LW had significantly narrower hips compared to both the N and O women suggesting a more linear physique of the LW women.

In comparing the somatotypes of the open male rowers, O rowers were more mesomorphic and endomorphic than the LW rowers (O: 1.9-5.0-2.5; LW: 1.4-4.4-3.4). Similar differences were seen with the female rowers (O: 2.8-3.8-2.6; LW: 2.0-3.5-3.3) and reflects the requirements of a weight category event. The somatotypes for the comparison group were 2.7-5.0-2.8 for the males and 4.7-4.0-2.1 for the females.

Relative body size

Given the significant absolute size differences between O rowers and the other groups, further analysis was required to expose any differences in body segment proportions. These proportionality characteristics (Zp) of male and female rowers are presented in Table 2, while Figures 3 and 4 display the proportionality differences between the rowing groups and N for male and female sub-samples respectively.

Insert Table 2, and Figures 3 and 4 about here

Table 2 shows O rowers to possess markedly higher proportional body mass (Zp body mass) compared to both LW and N ($p<0.01$). Thus, not only are O heavier in absolute terms, male and female O rowers are almost 1.5 and 1.0 standard scores greater than N respectively, when scaled to a common stature (Figures 3 and 4). Female LW rowers are more than 0.5 standard scores below N. Since these groups were of similar stature, this result confirms the imperative for female LW rowers to minimise adiposity, yet maximise lean tissue within the weight limits imposed by the sport.

With the exception of the Zp body mass parameter, male O and LW rowers demonstrate similarity in the pattern of segment proportions compared to N (Figure 3), though O are more disparate from N in several features. O rowers are more than 0.5 standard scores greater than N on measures of proportional upper arm and lower leg lengths, proportional chest depth, and corrected chest, waist and mid-thigh girths. Yet, despite a greater absolute hip girth, O rowers possess a significantly ($p<0.01$) lower Zp hip girth compared to N. Similarly, O rowers possess a shorter Zp sitting height compared to N, even though this variable is greater in absolute terms.

Figure 4 shows a similar pattern of segment proportions between the O and LW female rowers. The O rowers were more than 0.5 standard phantom Z-scores greater than N in measures of proportional limb girths (corrected arm, chest, waist and mid-thigh girths). Clearly, O rowers possess significantly smaller proportional scores for chest depth, hip breadth and hip girth, despite being larger than N in absolute size. The LW female rowers demonstrate similar traits for these variables, with proportional phantom Z-scores at least 1.0 standard scores below N.

Best versus rest

As shown in Table 3, the higher placed male O rowers were significantly taller and heavier, and had a greater sitting height ($p < 0.01$ respectively) compared to the rest. They were also more muscular as indicated by larger relaxed arm and forearm girths ($p < 0.01$ respectively). For the LW male rowers, only proportional thigh length was significantly greater in the best competitors ($p <0.01$). With regard to the O female rowers, the sum of 8 skinfolds was significantly lower ($p < 0.01$) for the more highly placed competitors compared to the rest.

Insert Table 3 about here

Discussion

According to Ackland (2005), the talent identification process involves five stages, the first of which requires an understanding of the important aspects for success in competition. In this regard, one must ask whether rowers demonstrate distinctiveness in physical capacities. Distinctiveness in human morphology that could lead to a competitive advantage within the sport of rowing may be demonstrated, according to Ackland (2005), by:

- homogeneity of physical structure among elite competitors;
- possession of unique physical capacities not commonly observed in the normal population; and/or
- significant differences between the best athletes and lower level competitors.

The data presented in this paper will be evaluated according to these three criteria in the first part of this discussion.

Do Olympic rowers exhibit homogeneity in physical structure?

Clear morphological differences exist between O and LW rowers, primarily due to the constraint on the weight of the latter group. Thus, for both male and female competitors, O rowers are taller, heavier and more robust than their LW counterparts. Furthermore, the O rowers possess a greater accumulation of subcutaneous adipose tissue than LW. Lower levels of body fat are commonly observed in female athletes in weight category or distance events (Brownell, Steen & Wilmore 1987).

However, when we stratify the sample according to gender and category, convincing evidence is revealed to confirm their homogeneity in physical structure. This sample of rowers contains competitors who vary greatly in quality, from medallists through to those who did not make the A or B finals. Yet, the variance in stature and body mass is very low for this athlete group, and among the lowest reported for similarly elite performers in other sports. This is especially so, and perhaps not surprising, for the LW rowers who must make strict weight targets for competition, but the observation applies similarly for the O rowers.

The rules for competition require that the average crew weight (excluding any coxswain) shall not exceed 70.0kg and 57.0kg for men and women LW rowers respectively, with no individual rower to exceed 72.5kg and 59.0kg respectively.

Furthermore, when one considers the SD values for other absolute size variables of the LW rower groups in Table 1, they are consistently about half the magnitude of the comparison group of healthy young adults. This is not so apparent for the O rowers, however, with the exception of height and weight variables as mentioned above, as well as corrected chest, waist and hip girths. With respect to adiposity, all rower groups display little variance in the sum of 8 skinfolds compared to N.

Therefore, these data suggest that Olympic rowers do exhibit homogeneity in physical structure.

Do Olympic rowers possess unique physical characteristics?

Bloomfield (Bloomfield 1979) described the concept of self-selection for sport as being akin to the evolutionary process, whereby athletes with appropriate traits to provide a competitive advantage survive in the sport and achieve higher ranking. This *lassaiz faire* approach has been overtaken with the advent of modern national sport systems and their emphasis on talent identification programmes (Bloomfield, Ackland & Elliot 1994). Nevertheless, sports scientists and coaches endeavour to select individuals based on these unique and identifiable physical, physiological and psychological characteristics.

In terms of absolute size, both male and female O rowers are taller, heavier and leaner than their respective comparison group of healthy young adults, with significant differences in most measures of segment length, breadth and girth. However, after scaling for stature, male O rowers are still proportionally heavier than N with greater proportional chest, waist and thigh dimensions. Open female rowers are also proportionally heavier than N with greater proportional arm, chest, waist and thigh dimensions (except proportional chest depth). These characteristics relate specifically to the muscle development and lung capacity requirements of elite rowers.

Of particular note, O rowers possess a proportionally smaller hip girth than N. This characteristic is common across all rower categories and suggests the equipment they use places some constraint on this parameter. That is, boat fluid mechanics supports the design of long, narrow hull shapes for minimising resistance to forward motion. Among the female rowers, this trait is supported by the very low proportional hip breadth in comparison to N.

The LW rowers were similar to N in stature and limb lengths for both the male and female sub-samples. DeRose et al. (1989) found male LW rowers from the Pan American Games to be similar to student controls with the exception of a short sitting height and a large transverse chest depth, however this was not the case in the present study. The female LW rowers in the study by DeRose et al. were generally larger than the reference sample for most measurements with the exception of skinfold thicknesses and sitting height. However, female LW rowers in this study were leaner and had a smaller hip girth compared to N, but there was no difference in sitting height. The present study provided data from a larger sample of more elite level male LW rowers than that of DeRose et al. (1989), but both studies recruited only a small number of female LW participants. The Sydney Olympic Games had only one event for LW females so only a small number of rowers were available for testing. Therefore, a larger sample of LW female rowers is needed to be able to identify possible unique physique characteristics.

The proportionality profile of LW rowers mirrors that of the O competitors for most variables when compared to N (Figures 3 and 4). In general, the proportional girth and segment breadth values for the LW competitors in these figures are shifted to the left with respect to O rowers. However, there is less of a disparity with respect to proportional segment lengths. This result suggests that LW rowers are not simply scaled down versions of the O rower morphology. In summary, LW rowers appear to retain the advantageous segment length proportions of the O rower, yet the imposition of a weight limit for LW competition has the effect of preferentially selecting rowers with a lean and linear physique.

In summary, these data suggest that Olympic rowers do possess unique physical characteristics when compared to the normal population

Are there significant differences between Olympic rowers of varying rank?

The differences reported between higher ranked rowers and the remaining competitors were few, which supports the notion of homogeneity in physique for competitors in this sport at the elite level. There were some significant differences, however, which serve to emphasise the critical variables for success in rowing.

Among O male rowers, for example, size definitely matters. The best competitors were able to maximise segment lengths, girths and breadths, yet still conform to the performance constraints necessary to fit into the rowing shell. Therefore the boat width may act as a homogenising constraint. That is, while several adjustments to the boat rigging are possible to accommodate rowers of varying length, their hips and buttocks must fit into a seat that slides within a pre-determined boat width. This physical restriction is particularly evident among female rowers, with the best performers having significantly less adiposity ($p<0.01$), and showing a trend ($p<0.05$) toward proportionally narrower hips.

The international governing body for rowing (FISA) does not stipulate maximum or minimum boat widths for competition, but instead publishes minimum boat weights in each event category. Thus, the manufacturer is free to design the most advantageous hull shape within this limitation, generally opting for long and narrow designs. The external width of the boats (gunwale width) varies according to the type of boat (from single scull to a full racing eight) as well as the crew location within the boat. Data from all equipment measured at the 2000 Olympics, show this dimension varies from 40.0 – 68.5 cm.

Changes in physical characteristics over time

A later stage in the talent identification process requires the compilation of a set of normative data on elite performers for comparison purposes. According to Ackland (2005), outdated normative data sets are of limited utility when the sport experiences substantial changes in rules, equipment, and athlete preparation strategies. Therefore, coaches should always seek to use the most up-to-date comparison data when creating an individual profile. The results for Olympic rowers measured at the 2000 Olympic games will be compared to other published scores to adjudge the utility of the present information as a normative data set for profiling elite rowers.

The last comprehensive anthropometric survey of elite rowers was conducted at the 1976 Montreal Olympic Games (Carter 1982). The Sydney Olympic male O rowers were taller (193.3 cm vs 188.6 cm; diff = 4.7 cm) and heavier (93.6 kg vs 87.2 kg; diff = 6.4 kg) in comparison to the Montreal Olympic rowers (Carter 1982). Similarly the Sydney Olympic female O rowers were taller (180.8 cm vs 175.2 cm; diff = 5.6 cm) and heavier (76.6 kg vs 64.5 kg; diff = 12.1 kg) than those from the Montreal Olympics.

According to Norton and Olds (1996), the secular trend in the population toward greater body size was relatively steady from the early part of the 20th Century. The average trend for stature was reported as being 1.23 and 1.33 cm per decade for women and men respectively. Thus, we might expect differences between the Montreal and Sydney Olympic samples of approximately 3.2 cm based on the secular trend alone. Since no LW rowers competed at the Montreal Olympic Games, we could suppose that factors in addition to the population secular trend, such as current selection and training practices, may have influenced these differences in O rower morphology. Of course there may have been some bias related to the quality of these two samples, but at Montreal (Carter 1982) sufficient numbers were measured to minimise this effect.

Furthermore, coaches cannot simply select the largest athletes for O rowing competition. Clearly, there exists a contraindication for very large athletes due to the physical constraints of the rowing shell, as well as the added frontal resistance created when the boat displaces more water with a heavier crew. Thus, we suggest that the changes in O rower morphology over the past three decades represent ‘relative optimisation’ (optimal player size increases at a similar rate to the general population – Norton and Olds, 1996) with superimposed changes as a result of modern selection, dietary and training processes, as well as possible advances in boat and rigging design.

In contrast, the LW rowers must make a weight category, so they represent ‘absolute optimisation’ where a set physical characteristic is required for competition – in this case body mass. So, despite the secular trend for taller and heavier individuals, LW rowers are being drawn from an ever-diminishing proportion of the population. This is one aspect of the rules that could be addressed by FISA, with a view to increasing the weight limits of LW crews periodically.

Conclusion

Based on several criteria, the rowers in this sample demonstrate distinctiveness in morphology that distinguishes them from the normal population as well as other sports performers. These criteria include homogeneity in morphology within the athlete group, the possession of unique physical characteristics that set them apart from the average person, and selected differences between the best performers and the rest. Such distinctiveness in body size, composition and proportionality could lead to a competitive advantage for rowing, and might therefore form the basis for any talent identification and development programme.

Furthermore, the information presented here may also serve as useful normative or comparison data in the talent identification process. The data fulfil the utility criteria, as suggested by Ackland (2005), as being:

- relatively current;
- created using elite athletes of international calibre;
- derived from athletes who are homogeneous in morphology / capacity; and
- stratified by gender and event category.

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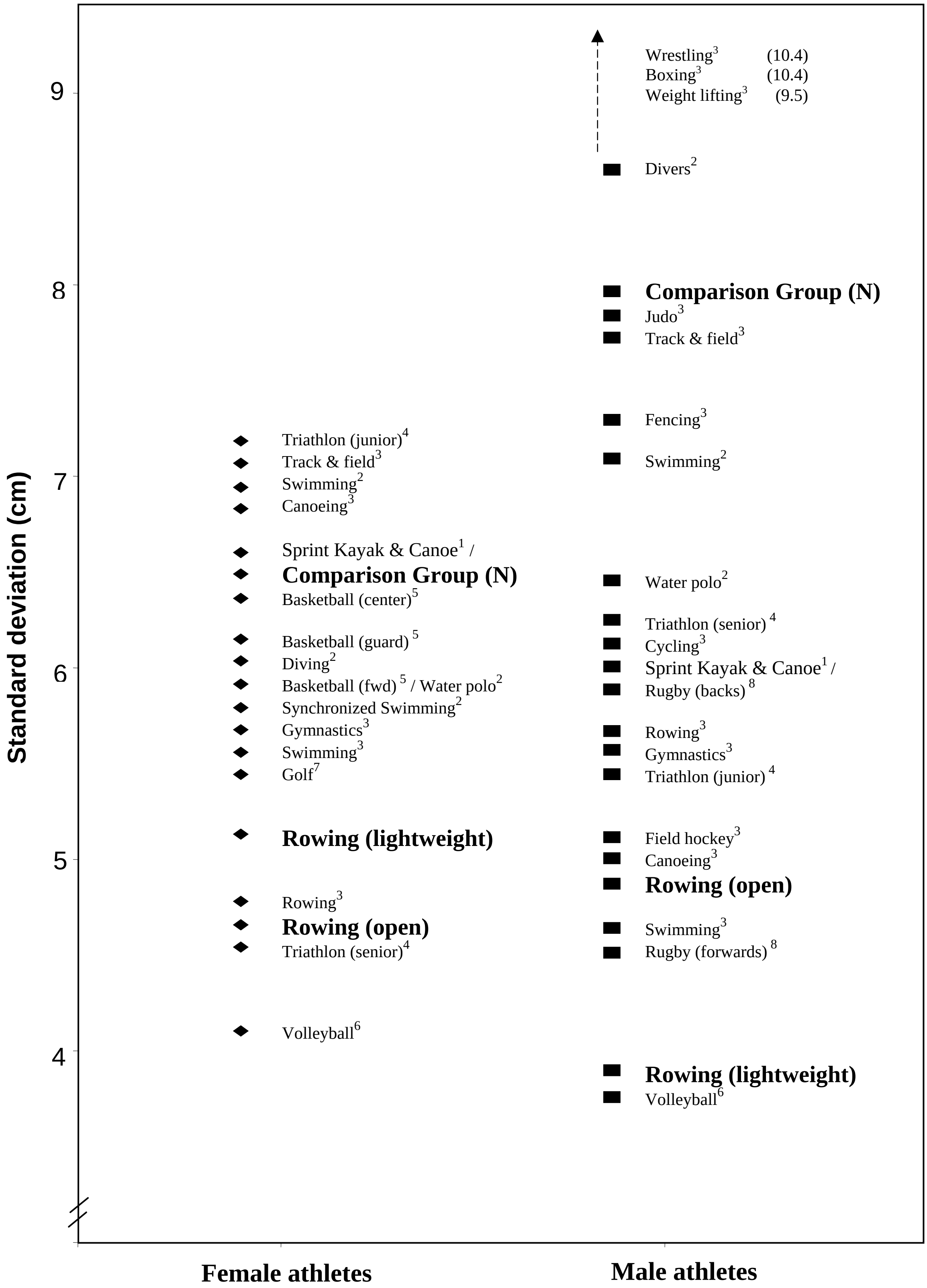
Figure 1. Standard deviation in stature of Olympic rowers in relation to elite athletes in other sports and the comparison groups of young adults.



1. Ackland et al. 2001
2. Carter & Ackland 1994
3. Carter 1982
4. Landers et al. 2000
5. Ackland, Schreiner & Kerr 1997
6. Puhl et al. 1982
7. Crews et al. 1984
8. Dacres-Manning 1990

Figure 2. Standard deviation in body mass of Olympic rowers in relation to elite athletes in other sports and the comparison groups of young adults.

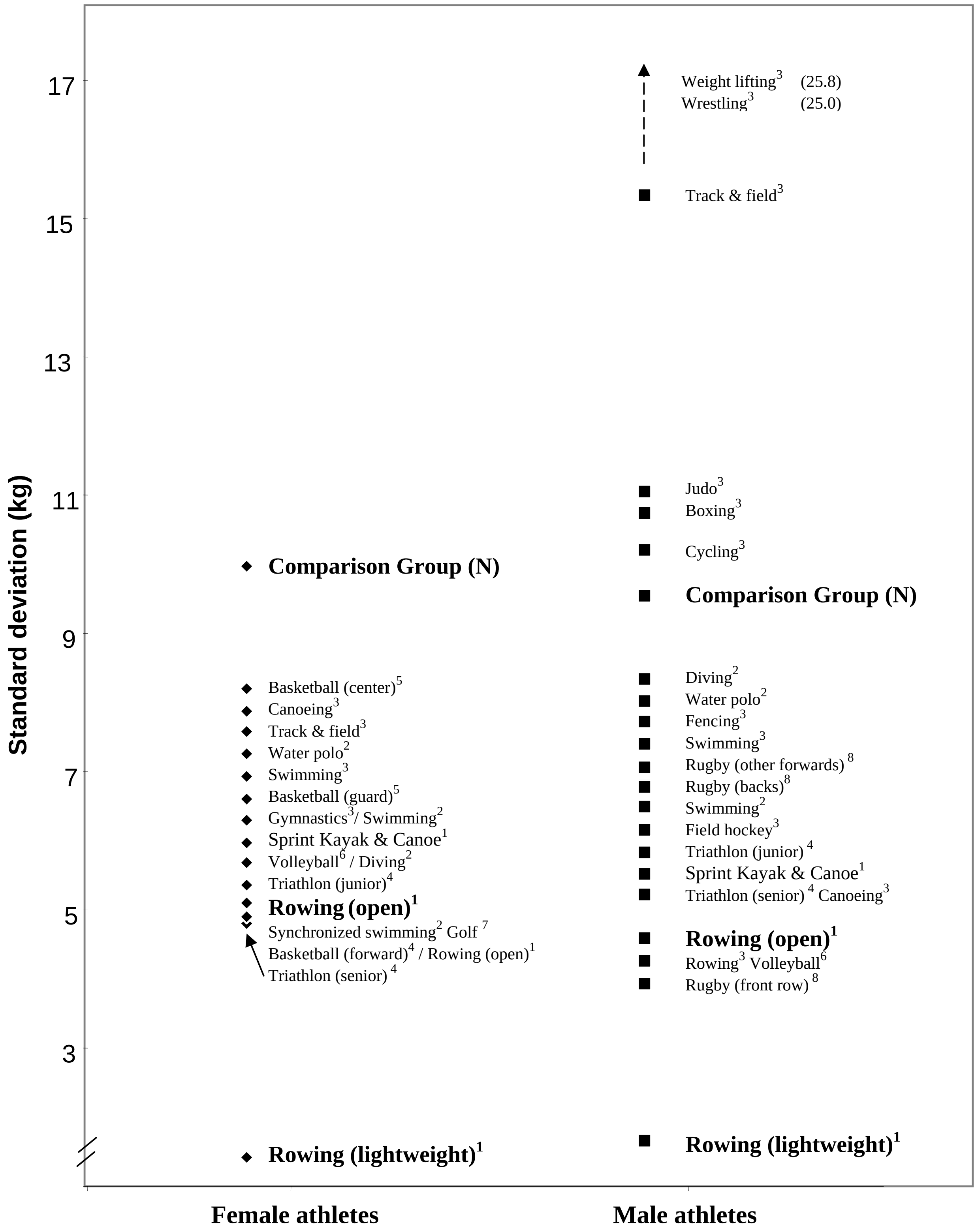


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Figure 3: Proportionality (phantom Z-scores) of male rowers comparing lightweight and open-class rowers

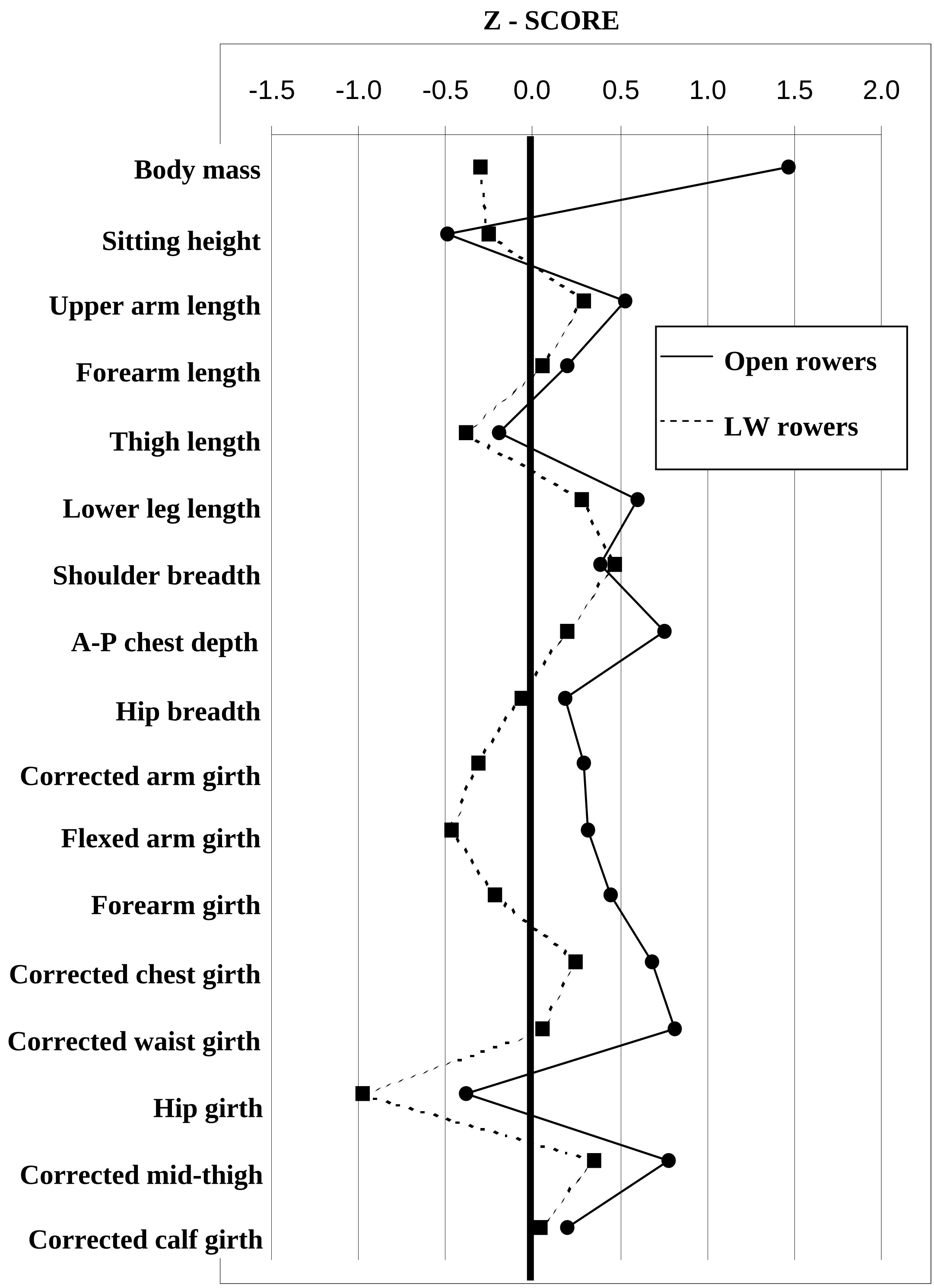

Figure 4: Proportionality (phantom Z-scores) of female rowers comparing lightweight and open-class owers

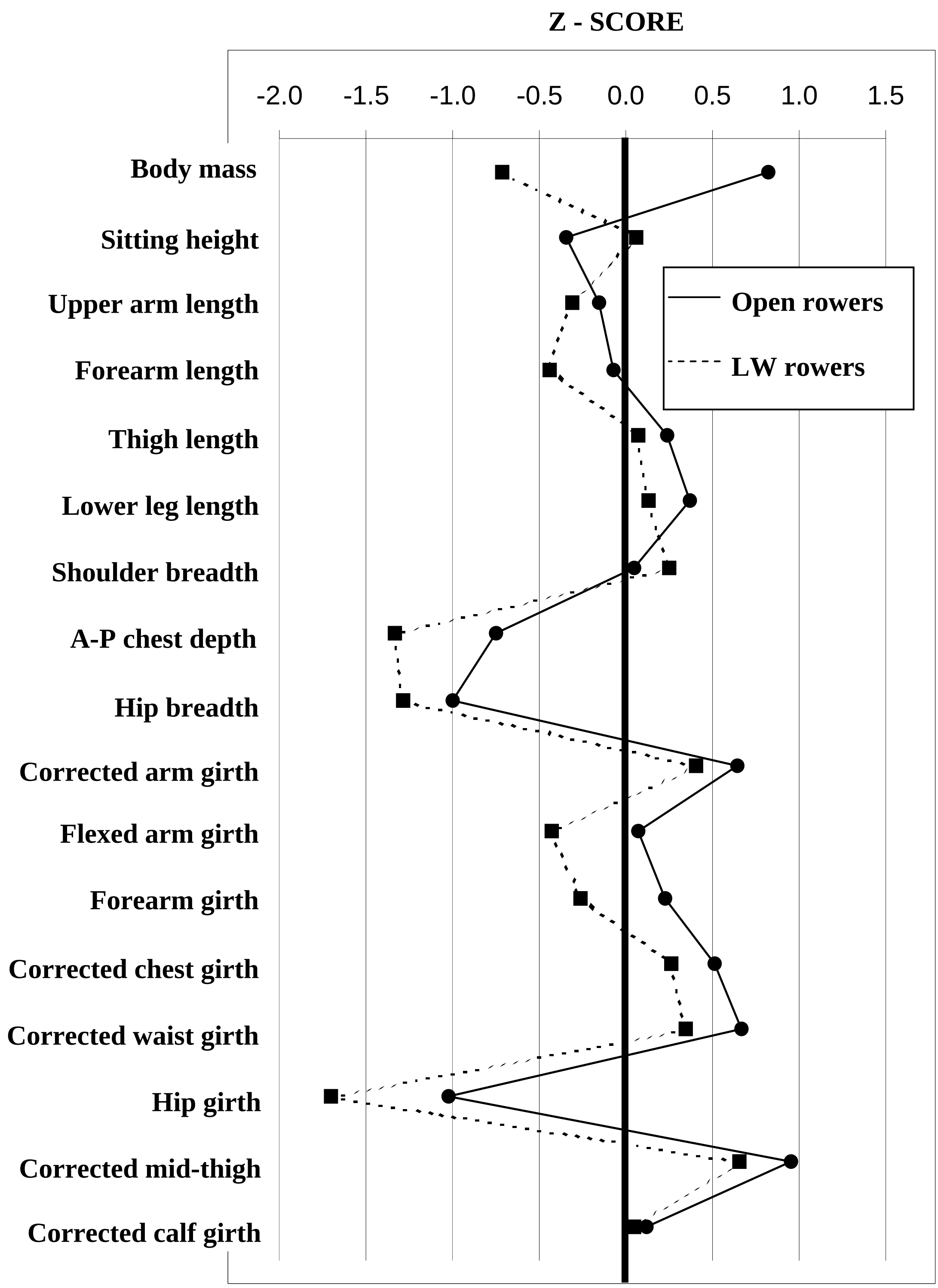

Table 1. Absolute size characteristics (M ± SD) of Olympic lightweight and open rowers, and comparison groups of young adults*

Variable	Males				Females			
	F-ratio (* = p<0.01)	Comparison group (n=42)	Lightweight (n=50)	Open (n=140)	F-ratio (* = p<0.01)	Comparison group (n=71)	Lightweight (n=14)	Open (n=69)
Age (y)	17.3*	22.6±5.3 [a,b]	27.1±4.1 [c]	26.4±3.6	12.6*	30.5±3.3 [a,b]	26.0±2.9	27.8±4.4
Body mass (kg)	316.8*	74.5±9.6 [a]	72.5±1.8 [c]	94.3±5.9	56.2*	64.5±10.2 [a]	58.5±1.5 [c]	76.6±5.2
Sum 8 skinfolds (mm)#	41.4*	83.0±34.6 [a,b]	44.7±8.1 [c]	65.3±17.3	39.9*	138.3±51.5 [a,b]	59.7±12.4 [c]	89.0±23.6
Stature (cm)	142.8*	180.1±7.9 [a]	182.1±3.8 [c]	193.3±4.9	90.1*	168.3±6.5 [a]	169.2±5.1 [c]	180.8±4.7
Sitting height (cm)	58.8*	94.7±4.2 [a]	94.6±2.7 [c]	99.2±2.9	36.9*	88.8±3.7 [a]	89.5±3.5 [c]	93.7±3.1
Upper arm length (cm)	112.6*	34.2±1.8 [a]	35.1±1.6 [c]	37.8±1.5	36.8*	32.7±1.7 [a]	32.3±1.5 [c]	34.9±1.5
Forearm length (cm)	58.0*	26.6±2.1 [a]	26.9±1.0 [c]	28.8±1.3	38.5*	24.4±1.3 [a]	24.0±0.9 [c]	26.1±1.2
Thigh length (cm)	43.9*	47.1±2.8 [a]	46.6±2.0 [c]	50.1±2.7	48.2*	43.5±2.3 [a]	43.9±1.8 [c]	47.4±2.5
Lower leg length (cm)	132.3*	47.8±2.4 [a,b]	49.1±2.0 [c]	53.1±2.0	76.7*	44.2±2.3 [a]	44.7±1.9 [c]	48.4±1.9
Shoulder breadth (cm)	82.4*	39.9±2.0 [a,b]	41.4±1.5 [c]	43.7±1.9	53.2*	36.6±2.0 [a]	37.2±1.5 [c]	39.4±1.2
Chest depth (cm)	40.9*	19.6±3.5 [a,b]	20.1±1.3 [c]	22.2±1.4	9.2*	19.2±1.8 [b]	17.5±0.6 [c]	19.5±1.5
Hip breadth (cm)	75.8*	28.3±1.6 [a]	28.5±1.2 [c]	30.8±1.4	7.7*	29.6±2.3 [b]	27.5±1.0 [c]	30.0±1.9
Corrected arm girth (cm)	74.2*	28.3±2.6 [a]	27.8±1.2 [c]	31.1±1.9	60.7*	22.5±2.0 [a]	23.5±1.5 [c]	25.7±1.5
Flexed arm girth (cm)	118.6*	33.2±2.6 [a]	32.4±1.2 [c]	36.5±1.8	29.1*	29.1±2.6 [a]	28.2±1.1 [c]	31.4±1.5
Forearm girth (cm)	133.8*	28.2±1.6 [a]	28.2±0.8 [c]	31.0±1.3	57.6*	24.8±1.5 [a]	24.5±0.8 [c]	27.0±1.0
Corrected chest girth (cm)	145.4*	94.9±5.3 [a]	97.4±3.2 [c]	105.9±4.3	87.5*	83.3±4.9 [a]	85.0±2.4 [c]	92.2±3.3
Corrected waist girth (cm)	196.0*	74.2±4.2 [a]	75.4±3.4 [c]	83.8±3.1	63.4*	65.0±5.2 [a]	66.8±2.1 [c]	72.9±3.3
Hip girth (cm)	121.2*	97.6±6.0 [a,b]	92.9±2.3 [c]	102.4±3.3	19.7*	99.5±7.1 [b]	90.5±2.4 [c]	100.8±3.5
Corrected mid-thigh girth (cm)	166.3*	48.4±3.1 [a,b]	50.6±1.5 [c]	55.8±2.7	104.6*	43.2±3.3 [a, b]	46.1±1.6 [c]	50.6±3.0
Corrected calf girth (cm)	55.8*	34.2±2.1 [a]	34.7±1.6 [c]	37.3±2.1	29.7*	31.5±2.2 [a]	31.8±2.4 [c]	34.1±1.8

a = comparison group significantly different from open-class rowers at p<0.01; b = comparison group significantly different from lightweight rowers at p<0.01
c = lightweight significantly different from open-class rowers at p<0.01
* non-parametric test (Kruskal-Wallis test) for K independent samples was applied to the sample to test significance. A non-parametric test for 2 independent samples was used to identify which groups were significantly different
# sum of 8 skinfolds = triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medical calf

Table 2: Relative size characteristics calculated from Phantom Z-scores of Olympic lightweight and open rowers, and comparison groups of young adults

Proportionality Variable	Males				Females			
	F-ratio (* = p<0.01)	Comparison group (n=42)	Lightweight (n=50)	Open (n=140)	F-ratio (* = p<0.01)	Comparison group (n=71)	Lightweight (n=14)	Open (n=69)
Z Body mass	238.6*	0.67 [a]	0.37 [c]	2.14	30.3*	0.06 [a, b]	-0.66 [c]	0.88
Z Sitting height	19.9*	-0.08 [a]	-0.33 [c]	-0.57	10.8*	-0.02	0.04	-0.37
Z Upper arm length	15.0*	-0.13 [a]	0.16	0.40	2.0	0.31	0.00	0.16
Z Forearm length	1.2	0.39	0.45	0.59	2.6	0.10	-0.34	0.03
Z Thigh length	3.7	1.28 [b]	0.89	1.09	2.1	1.07	1.14	1.31
Z Lower leg length	26.6*	0.14 [a]	0.42 [c]	0.74	10.3*	-0.06 [a]	0.07	0.31
Z Shoulder breadth	4.3	-0.15 [a, b]	0.32	0.24	0.5	-0.54	-0.29	-0.49
Z Chest depth	6.9*	0.74 [a]	0.94 [c]	1.50	12.2*	1.39 [a, b]	0.06	0.64
Z Hip breadth	3.1	-1.17	-1.23 [c]	-0.98	18.3*	0.64 [a, b]	-0.65	-0.36
Z Corrected arm girth	10.4*	-0.06	-0.37 [c]	0.23	12.6*	-1.78 [a]	-1.38	-1.14
Z Flexed arm girth	18.6*	0.85 [b]	0.38 [c]	1.16	1.8	0.01	-0.42	0.08
Z Forearm girth	11.1*	1.08	0.86 [c]	1.53	2.2	-0.03	-0.29	0.20
Z Corrected chest girth	12.4*	0.37 [a]	0.62 [c]	1.05	7.5*	-0.70 [a]	-0.44	-0.19
Z Corrected waist girth	28.9*	-0.38 [a]	-0.32 [c]	0.43	8.8*	-1.39 [a]	-1.04	-0.72
Z Hip girth	29.4*	-0.42 [a, b]	-1.40 [c]	-0.81	29.8*	1.08 [a, b]	-0.62 [c]	0.06
Z Corrected mid-thigh girth	28.9*	-2.36 [b]	-2.01 [c]	-1.58	30.7*	-2.87 [a, b]	-2.21	-1.92
Z Corrected calf girth	1.3	-1.26	-1.22	-1.06	0.4	-1.47	-1.42	-1.35

a = comparison group significantly different from open-class rowers at p<0.01; b = comparison group significantly different from lightweight rowers at p<0.01
c = lightweight significantly different from open-class rowers at p<0.01
* non-parametric test (Kruskal-Wallis test) for K independent samples was applied to the sample to test significance. A non-parametric test for 2 independent samples was used to identify which groups were significantly different

Table 3. ANOVA results summary and descriptive statistics (M ± SD) for variables that showed a significant difference (p<0.01) or trend (p<0.05) between highly ranked (top 7 places = BEST) and those ranked lower (REST).

Measure	F-ratio	BEST	REST
Open male rowers: #			
Stretch stature (cm)	8.062 [a]	194.1 ± 4.4	191.5 ± 5.7
Sitting height (cm)	9.473 [a]	99.7 ± 2.7	98.1 ± 2.9
Body mass (kg)	10.657 [a]	95.3 ± 5.4	91.9 ± 6.4
Arm girth (relaxed) (cm)	6.985 [a]	33.8 ± 1.8	32.9 ± 2.0
Arm girth (flexed) (cm)	6.340 [a]	36.8 ± 1.7	35.9 ± 1.9
Forearm girth (cm)	8.440 [a]	31.2 ± 1.3	30.5 ± 1.3
Chest girth (cm)	4.772 [b]	109.2 ± 4.0	107.5 ± 4.7
Biacromial breadth (cm)	6.103 [b]	44.0 ± 1.9	43.1 ± 1.7
Z forearm length	4.539 [b]	0.509 ± 0.670	0.781 ± 0.737
Lightweight male rowers: ^			
Biiliocristal breadth (cm)	6.923 [b]	28.1 ± 1.2	28.9 ± 1.1
Z thigh length	7.330 [a]	1.155 ± 0.619	0.670 ± 0.637
Open female rowers: *			
Sum 8 skinfolds (mm)	10.463 [a]	82.1 ± 23.2	99.8 ± 20.4
Endomorphy	4.498 [b]	2.62 ± 0.80	3.00 ± 0.62
Z biiliocristal breadth	4.176 [b]	-.186 ± 0.840	-.628 ± 0.927

[a] $p < 0.01$, [b] $p < 0.05$
= BEST open male rowers (n = 99); REST (n = 41)
^ = BEST lightweight male rowers (n = 23); REST (n = 27)
* = BEST open female rowers (n = 42); REST (n = 27)